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Sustainable coastal ecosystem management – An evolving paradigm and its application to Caribbean SIDS

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ABSTRACT

With our growing global population, over-consumption of natural resources and concomitant depletion, demands are placed on the scientific community to provide information, including suitable management of coastal ecosystems. However, the nature-society relationship is highly dynamic and complex and requires a framework which can accommodate options. In coastal systems, poor resource management is among the main causes of its degradation. As such, impacts arising from climate change, including sea-level rise, has forced an increase in the demand for sustainable coastal ecosystem science to inform management decisions. The realization of current and future sustainability objectives depends on the development and implementation of coherent strategies on managing dynamic ecosystems for retaining their ability to undergo disturbance, while maintaining their services, functions and control mechanisms. This paper provides a review of the basic assumptions, typical frameworks and methodologies that are adopted for (i) sustainability and sustainable management, (ii) ecosystem services and ecosystem management and (iii) coastal ecosystem management applications in Caribbean Small Island Developing States (SIDS). Finally, limitations for sustainable coastal ecosystem management are discussed and recommendations are made which can inform research in sustainability science.

1. Introduction

An ecosystem is a community of plants and animals (biotic) interacting with each other and the non-living community (abiotic) in a geographic space which collectively support a number of services which are vital for ecosystem functioning and human wellbeing (Millennium Ecosystem Assessment, 2005). Such intricate systems are found in various forms in both the terrestrial and marine environments. However, despite the interlinkages and significant degree of co dependence between ecosystem services and human economic, social and cultural wellbeing, it is globally recognised that pressures arising from population growth and anthropogenic activities are among the major culprits of ecosystem damage and degradation. According to the United Nations, approximately 60 percent of the ecosystems are being degraded at a rate many times more than they can replenish themselves or build resilience (Millennium Ecosystem Assessment, 2005).

There are many potential fallouts which over time will result in changes to the planetary boundaries in such a manner that it compromises the way society functions and live (Rockström et al., 2009). One of the areas to be much affected is the coastal areas where 13% of the world's population reside (McGranahan et al., 2007; Smith, 2011) and more significantly in Small Island Developing States (SIDS) where the coastal population is typically between 50 and 90% of the total population (UNFCCC, 2005; Marto et al., 2014). The coastal belt is recognised to be one of the most vulnerable areas to exogenous activities such as effects of climate change and natural disasters (Nicholls et al., 2007; Kron, 2013), and is also one of the most complex geographical and geophysical zone due to the multi interactions of various activities. As such, science is an important cornerstone to understanding these complexities and to guide better policies to support sustainable development (Nicholls, 2004; Visbeck et al., 2014). However, despite the role of science in promoting these linkages, some of the ecosystem frameworks, while contributing to better understanding, possess many gaps in terms of their practical applications (Hein et al., 2006; Boyd and Banzhaf, 2007; Fisher et al., 2007; Martín-López, 2009), which if addressed could allow science to play a more active role in management.

Taking these observations into consideration, this paper seeks to review the key developments in sustainable coastal ecosystem science. In doing so, the evolution of frameworks and concepts will be discussed and the gaps will be identified which can inform emerging research and

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direct better research governance in the coastal environment. Further, the application of sustainable coastal ecosystem management and the challenges in Caribbean SIDS is discussed and recommendations provided for improvement.

2. Method

To identify relevant studies for this review, a literature search primarily using Google Scholar and Primo Central was conducted. Keywords and combination of the terms 'sustainability', 'sustainable management', 'ecosystem services', 'ecosystem management', 'coastal management', 'coastal zone management' 'small island developing states', 'SIDS', 'framework' and 'assessment' were used to locate relevant information. The reference material obtained from these results consisted of 379 articles which were then classified into each thematic section of this paper (sustainability, ecosystem services, coastal management and SIDS), and evaluated based on the theoretical foundations, definitions and its contribution to the evolution of the discipline.

In cases where information was missing and to attain a chronological sequence within each theme, additional search approaches were used. The reference lists of relevant articles were scanned for appropriate secondary references (snowballing), and Google Scholar was further utilized to find suitable papers within the list of publications that have cited the relevant articles (reverse snowballing). For further context of the discipline's progression into more place-specific approaches and analysis, a focus on SIDS, in which a case study of Grande Riviere, a coastal ecosystem found in Trinidad was included in this study.

3. Sustainability and sustainable management

A standard perception of the environment was one that was anthropocentric and irresponsible prior to the writings of Leopold (1949) and Carson (1962) which shifted the paradigm of environmental awareness to one that was biocentric and cognizant. Later on, the environment and the exploitation of natural resources achieved global recognition with the Stockholm Declaration (Stockholm Declaration, 1972), the World Conservation Strategy (IUCN, 1980) and the Brundtland Report (WCED, 1987) (Fig. 1). The World Conservation Strategy (IUCN, 1980) was the first international document which promoted conservation of the living world for development to be sustainable and laid the foundations for the Brundtland Report, defining the principle of sustainable development (WCED, 1987).

In the early 1990s, the environment again took the forefront of discussion in the international environmental management architecture with the convening of the Earth Summit in 1992. Arguably, the concept of sustainable development became a global phenomenon enshrined in many guidelines and conventions. Currently, it is one of the most expressed strategic aim in national, regional and global economic, social and environmental policies. The concept of sustainable development continues to be mainstreamed in various forms and is regarded as one of the leading drivers of the global environmental agenda. These include resource management (IUCN, 1980), global environmental advocacy and governance (WCED, 1987; UNCED, 1992; UNWSSD, 2002). At this juncture, the concept of sustainable development while globally accepted and politically applauded, in the academic circle it was regarded a 'nebulous' with little traction and perhaps absent in the SIDS research agenda.

This concept also started influencing science and applied research which led to the emergence of a new research program called "sustainability science" by the National Research Council (1999) and Clark and Dickson (2003) highlighted the major movements in the transition toward sustainability. The editorial piece by Komiyama and Takeuchi (2006) entitled "Sustainability science: building a new discipline: which introduced the Journal of Sustainability Science marked the acceptance of this concept into the academic circle. As sustainability science became more popular, the notion of interdisciplinary approaches became more recognized as the tool to capture the inter-relationship and inter-connectivity of the various uses, processes and functions of the natural environment. What is evident here is that this has triggered more interdisciplinary approaches to environment and development which started a paradigm shift. The environment-economic-social nexus became more mainstreamed in dialogue, development programmes, policy and agenda. Currently, environmental management and biodiversity preservation are regarded as enablers to drive economic development towards increasing societal wellbeing. The objective of retaining the natural environment even if no benefits are realized by humans (IUCN, 1980; WCED, 1987) shifted to a focus on the variables that determine how an ecosystem caters to society's demands (UNCED, 1992; UNWSSD, 2002; MEA, 2005). This then further evolved to decision-making based on evaluating the risks and benefits of possible outcomes that affect the maintenance of natural capital (Bass and Dalal-Clayton, 2012; Roehrl, 2012). However, there remained the challenge of resource accounting.

Despite the evolution in the dialogue and acceptance of the concept, fundamental differences exist over what kind of future is desired and what should be sustained. Barbier (1987) intertwined sustainability with social dimensions, discussing social sustainability as "the ability to maintain desired social values, traditions, institution, cultures or other social characteristics." Lele (1991) wrote of "the existence of ecological conditions necessary to support human life at a specified level of well-being through future generations" as ecological sustainability (Fig. 1). These are among the many applications which reinforce the idea that sustainability science is not an autonomous field, but a current research theme that incorporates knowledge, practice and spatial scales across numerous fields of study with a broad scope that is consistently evolving and currently in a state of flux. One of the issues with sustainability science is that it considers units of the environmental system rather than a consideration of the entire system.

4. Ecosystem services and ecosystem management

The notion of ecosystem services further propelled the approach to environmental management from the recognition that no single component (or species) can be managed without considering the whole (or ecosystem). Inter-linkage in an ecosystem is significant and therefore, environmental management became improved through ecosystem-based approaches. The role of ecosystems in delivering services to society was first discussed in the 1970s by (Mooney and Ehrlich, 1977) and was first termed 'ecosystem services' a decade later (Ehrlich and Ehrlich, 1981).

Ecosystem services has been increasing in popularity since the common 1997 definitions (Daily, 1997; Costanza et al., 1997). It has since been applied or considered in various sectors such as fisheries (Holmlund and Hammer, 1999; Link, 2002; Hoeinghaus et al., 2009), forestry (Nasi et al., 2002), land use planning (Burkhard et al., 2009) and coastal settlement (Adger et al., 2005; Maass et al., 2005; Singh, 2016).

Now it is generally regarded as the option for management and is widely used in coastal zone management (Levin and Lubchenco, 2008; Nobre and Ferreira, 2009; Granek et al., 2010), ocean management (Blasiak et al., 2014; Foley et al., 2013), protected areas (Cruz et al., 2011; Allendorf and Yang, 2013) ocean governance and management (Levin et al., 2009; UNEP, 2009; Arkema et al., 2015; Singh et al., 2015) forestry management (Uhde et al., 2015) and biodiversity (Haines-Young and Potschin, 2010; Mace et al., 2012) among others. This concept has gained traction because it offers a modality to incorporate measurable and non-measurable aspects of the environment, integrating social, economic and ecological perspectives to facilitate the development of appropriate policies and management strategies.

In 2003, the United Nations gave more global recognition to links between ecosystem change and human well-being championed through

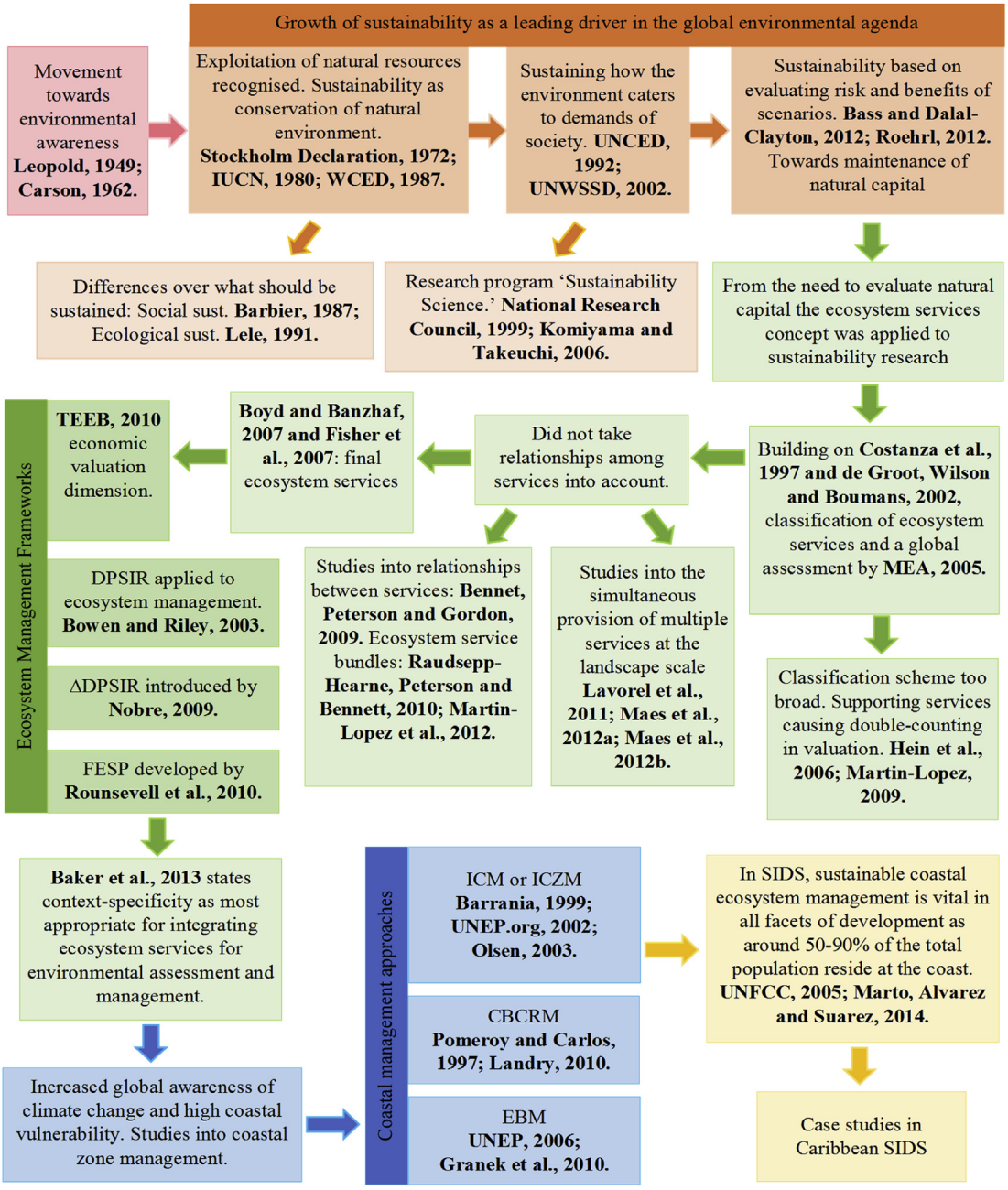
Growth of sustainability as a leading driver in the global environmental agenda
Movement towards environmental awareness Leopold, 1949; Carson, 1962.
Exploitation of natural resources recognised. Sustainability as conservation of natural environment. Stockholm Declaration, 1972; IUCN, 1980; WCED, 1987.
Sustaining how the environment caters to demands of society. UNCED, 1992; UNWSSD, 2002.
Sustainability based on evaluating risk and benefits of scenarios. Bass and Dalal-Clayton, 2012; Roehrl, 2012. Towards maintenance of natural capital
Differences over what should be sustained: Social sust. Barbier, 1987; Ecological sust. Lele, 1991.
Research program 'Sustainability Science.' National Research Council, 1999; Komiyama and Takeuchi, 2006.
From the need to evaluate natural capital the ecosystem services concept was applied to sustainability research
Building on Costanza et al., 1997 and de Groot, Wilson and Boumans, 2002, classification of ecosystem services and a global assessment by MEA, 2005.
Did not take relationships among services into account.
Boyd and Banzhaf, 2007 and Fisher et al., 2007: final ecosystem services
TEEB, 2010 economic valuation dimension.
Studies into relationships between services: Bennet, Peterson and Gordon, 2009. Ecosystem service bundles: Raudsepp-Hearne, Peterson and Bennett, 2010; Martin-Lopez et al., 2012.
Studies into the simultaneous provision of multiple services at the landscape scale Lavorel et al., 2011; Maes et al., 2012a; Maes et al., 2012b.
Classification scheme too broad. Supporting services causing double-counting in valuation. Hein et al., 2006; Martin-Lopez, 2009.
Ecosystem Management Frameworks
DPSIR applied to ecosystem management. Bowen and Riley, 2003.
ΔDPSIR introduced by Nobre, 2009.
FESP developed by Rounsevell et al., 2010.
Baker et al., 2013 states context-specificity as most appropriate for integrating ecosystem services for environmental assessment and management.
Increased global awareness of climate change and high coastal vulnerability. Studies into coastal zone management.
Coastal management approaches
ICM or ICZM Barrania, 1999; UNEP.org, 2002; Olsen, 2003.
CBCRM Pomeroy and Carlos, 1997; Landry, 2010.
EBM UNEP, 2006; Granek et al., 2010.
In SIDS, sustainable coastal ecosystem management is vital in all facets of development as around 50-90% of the total population reside at the coast. UNFCC, 2005; Marto, Alvarez and Suarez, 2014.
Case studies in Caribbean SIDS

Fig. 1. Timeline of major developments in sustainable coastal ecosystem management.

its Millennium Ecosystem Assessment (MEA) building on previous classification systems posited by Costanza et al. (1997) and de Groot et al. (2002). The significance of the UNs work is the further classification of ecosystem services into four categories: provisioning, regulating, cultural and supporting services reflected in the Millennium Ecosystem Assessment report (2005) (Fig. 2). However, its broad scope and complexity meant that definitive information was not obtained for issues that were addressed, and its goal for directing policy initiatives was inconclusive.

These initial attempts at ecosystem management through ecosystem services however did not take relationships among services into consideration (Costanza et al., 1997; de Groot et al., 2002; Millennium Ecosystem Assessment, 2005). The broad classification scheme devised by the MEA, while being comprehensive, is not fit for all purposes. The category of supporting services was criticized for representing the ecological processes underlying the functioning of ecosystems, and for valuation purposes, it is argued that it will lead to double counting (Hein et al., 2006; Martín-López, 2009).

To avoid this drawback of double-counting, research began on the relationships between ecosystem services by Bennett et al. (2009) and Raudsepp-Hearne et al. (2010) introduced the concept of 'ecosystem service bundles' as sets of services that appear together repeatedly across space or time. This improved approach reduced the double counting discrepancies, highlighted opportunities of reducing trade-offs and creating or enhancing synergies, and, more importantly, was the first attempt at quantitative valuation of ecosystem services as a bundle. Bennett et al. (2009) explain that through an examination of the process that link services, the risk of regime shifts (sudden, unexpected, and likely undesirable changes) in ecosystem services can be reduced. Ecosystem service bundles has since been applied to support policy, management and land-use planning (Lavorel et al., 2011; Maes et al., 2012a, 2012b).

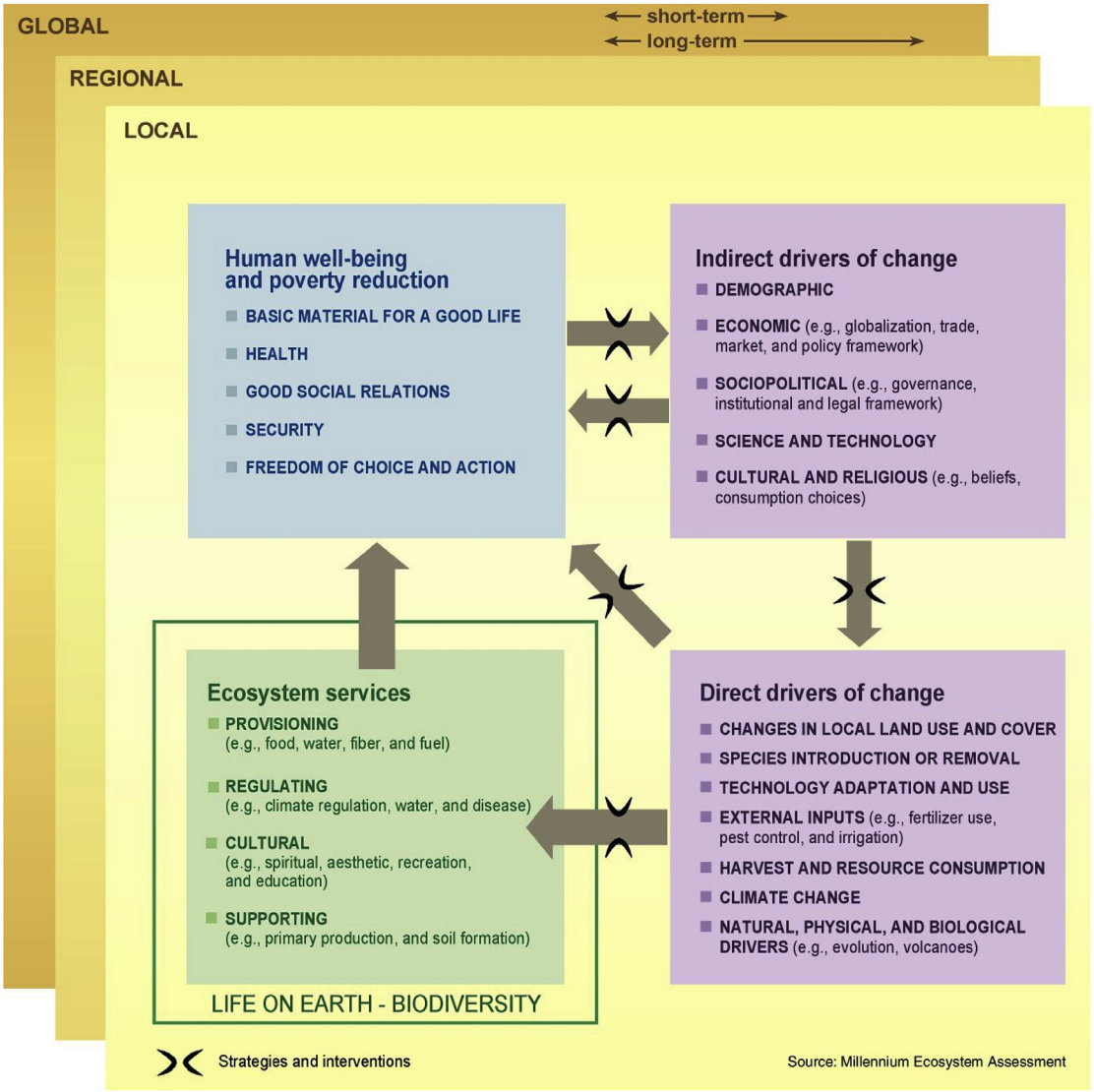
GLOBAL
short-term
long-term
REGIONAL
LOCAL
Human well-being and poverty reduction
BASIC MATERIAL FOR A GOOD LIFE
HEALTH
GOOD SOCIAL RELATIONS
SECURITY
FREEDOM OF CHOICE AND ACTION
Indirect drivers of change
DEMOGRAPHIC
ECONOMIC (e.g., globalization, trade, market, and policy framework)
SOCIOPOLITICAL (e.g., governance, institutional and legal framework)
SCIENCE AND TECHNOLOGY
CULTURAL AND RELIGIOUS (e.g., beliefs, consumption choices)
Ecosystem services
PROVISIONING (e.g., food, water, fiber, and fuel)
REGULATING (e.g., climate regulation, water, and disease)
CULTURAL (e.g., spiritual, aesthetic, recreation, and education)
SUPPORTING (e.g., primary production, and soil formation)
LIFE ON EARTH - BIODIVERSITY
Direct drivers of change
CHANGES IN LOCAL LAND USE AND COVER
SPECIES INTRODUCTION OR REMOVAL
TECHNOLOGY ADAPTATION AND USE
EXTERNAL INPUTS (e.g., fertilizer use, pest control, and irrigation)
HARVEST AND RESOURCE CONSUMPTION
CLIMATE CHANGE
NATURAL, PHYSICAL, AND BIOLOGICAL DRIVERS (e.g., evolution, volcanoes)
Strategies and interventions
Source: Millennium Ecosystem Assessment

Fig. 2. The Millennium Ecosystem Assessment conceptual framework and classification of ecosystem services (Source: MEA, 2005).

Most areas are used for multiple services. Raudsepp-Hearne et al. (2010) analysed the spatial patterns of ecosystem services which facilitated comparisons and an overview of where trade-offs and synergies may occur or are occurring. However, one of the criticisms of Raudsepp-Hearne et al. (2010) is the indicative rather than definitive approach, as it failed to predict how ecosystem processes and its delivery of services will change as a result of particular drivers. This is partly due to the complexity of interactions within ecosystems. In 2014, Van der Biest et al. (2014) enhanced this approach through the development of the Ecosystem Service Bundle Index (EBI). This is arguably the first attempt at a more holistic assessment. The EBI model (though still in a development stage) allows for qualitative assessments of the impacts of management scenarios on bundled service delivery through the integration of driving policies and processes.

An alternative direction to the ecosystem management paradigm was presented by Boyd and Banzhaf (2007) and Fisher et al. (2007) called the final ecosystem services. This refers to the aspects of ecosystems utilized either actively or passively to produce human well-being. By identifying services as only the directly consumable endpoint, research into the nature-society relationship or societal dependence on ecosystem services is made much clearer. This is arguably the first attempt at linking the environment and social wellbeing. By adopting human wellbeing as of the pillars to assess the ecosystem service, it became easier to identify with and appreciate the connection and services that the ecosystem provides in relation to mankind. Having realised this significant nature-society relationship, a new thrust toward valuing the ecosystem and biodiversity was realised via the new global initiative called The Economics of Ecosystems and Biodiversity (TEEB) which began in 2007. This initiative introduced an economic valuation dimension into ecosystem management decision-making (TEEB, 2010) (Fig. 3). This marked for the first time in which an economic construct was applied to valuing the environmental goods and services, which triggered a new global research agenda.

Another common approach used in ecosystem management is the Driver-Pressure-State-Impact-Response (DPSIR) framework. Devised for the European Water Framework Directive (WFD) (IMPRESS, 2002; Borja et al., 2006) DPSIR is popular with both managers and scientists for ecosystem management (Bowen and Riley, 2003). A number of modifications were done to the framework which was summarized by Singh (2005) and shown in Table 1. Among the advantages of the DPSIR and its variations is its ability to analyse the cause-effect relationship between human actions and environmental consequences through a systems approach (OECD, 1993; IIED, 2002; Singh 2005).

However, there are shortcomings to this approach such as DPSIR's inability to handle cause-consequence relationship, which is summarized in Singh (2005) and shown in Table 2. Over time, further changes

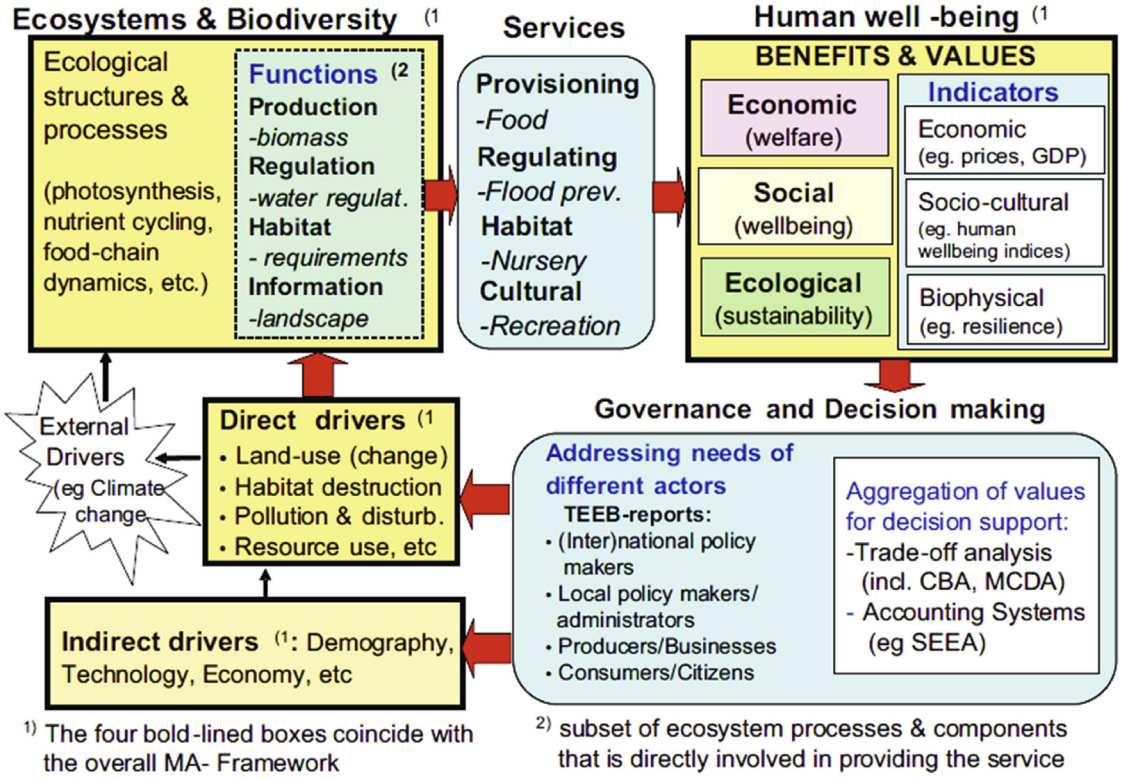

Fig. 3. The Economics of Ecosystems and Biodiversity (TEEB) conceptual framework (Source: TEEB, 2010).

were made including proposing a differential DPSIR (Nobre, 2009) which introduced a timeframe for the evaluation (Δt). While the differential DPSIR has its advantages, it lacks consideration of the social dimension where changes in employment and per capita income are monitored as it results from changing economic activity or policy implementation.

The Framework for Ecosystem Service Provision (FESP) was developed by Rounsevell et al. (2010) and is an adaptation of the DPSIR framework (Fig. 4). The definitions of DPSIR components and the recognition of Ecosystem Service Providers (ESPs) and Ecosystem Service Beneficiaries (ESBs) adds clarity toward ecosystem assessments and made this framework a key development in integrated social-ecological thinking. Other key innovations from this FESP are the differentiation between adaptation and mitigation responses which provides useful distinction for policy considerations, and improvement in the visual representation of directional relationships between components of the dynamic system (Fisher et al., 2013).

With developments in the ecosystem service paradigm, issues arise with respect to how the application of assessments is undertaken, as the constructed knowledge is being put to use. Challenges include the limits and assumptions of valuation methods (Hein et al., 2006; Fisher et al., 2009; Luisetti et al., 2011), the effective combination of disciplinary expertise in identifying critical thresholds in social-ecological systems (Potschin and Haines-Young, 2011), and the validation and development of tools for assessments (such as EBI (Ecosystem Service Bundle Index by Van der Biest et al., 2014); InVEST (Integrated Valuation of Ecosystem Services and Trade-offs by Kareiva et al., 2011); and ARIES (Artificial Intelligence for Ecosystem Services by Bagstad et al., 2011).

In an attempt to assess the impact of the newly evolving ecosystem services concept, Bull et al. (2016) undertook a SWOT analysis (strengths, weaknesses, opportunities, threats). The analysis highlighted the strengths of the ecosystem services concept has been its interdisciplinary nature and as a useful communication tool; weaknesses were its attempts to account for nature's intrinsic value and the inconsistent application of frameworks; opportunities included the ease of alignment with policies and ability to increase environmental awareness; and threats included the resistance to change, and difficulty with interdisciplinary collaboration (Bull et al., 2016).

Based on the progressive nature of ecosystem management, it is evident that it will be a continuously evolving tool since it is contingent on knowledge about the sensitivity of ecological functions and structures to particular drivers of change in different places. Despite developments toward a widely accepted conceptual framework, due to the interdisciplinary nature of this subject-area, frameworks for ecosystem management are likely to be either too complex for broad applications or unable to account for specific interactions. Baker et al. (2013) in a critical analysis of the role of ecosystem services for environmental assessments, indicates that the context as a defining factor, is the most appropriate way to integrate ecosystem services into environmental assessment practice. Thereby insinuating a 'one size fits all' does not work, as such, in addition to other context specific considerations, place-based approaches to ecosystem assessments are emerging.

5. Coastal management

Coastal management remains a challenge in both developed and developing countries when the effects of climate change are considered. Climate change is a major current research agenda since it is projected that over 70% of the coastlines worldwide may experience a sea level change within ± 20% of the global mean of 2.0 mm/yr (IPCC, 2014). Studies on the implications of sea-level rise on coastal communities are of particular interest to guide coastal management especially in low lying states with huge capital and infrastructural development in this area. The impacts of sea-level rise and related effects to the ecosystem are difficult to predict with any high degree of confidence although the general scientific understanding of coastal response to climate change is well established (Burkett and Davidson, 2012).

One of the challenges faced by scientists is the difficulty in integrating the social, environmental, and economic aspects of coastal zone ecosystems and the multiple-use interdependencies (Cicin-Sain

Table 1
Definitions used in the Variations of the DPSIR Framework.
(Source: Singh, 2005)

Framework	Driver (d)	Pressure (p)	State (s)	Impact (i)	Response (r)
SR Rapport and Friend (1979)	The Stress was defined as the activities that cause stress, the stress on the environment and the environmental response.				Actions taken by human to respond to the stress
PSR OECD (1983)	NA	Pressures are what the human society place on the environment, for example land use changes	The state refers to the condition of the environment that results from the exerted pressures, e.g. the levels of air pollution	NA	Actions taken by society either individually or collectively, that are designed to ease or prevent negative environmental impacts e.g. regulatory actions
DSR OECD (1994)	Human activities, processes and patterns that impact on the environment	NA	the state of sustainable development	NA	Policy options and other responses to changes in sustainable development
PSIR UNCSD (1996)	NA	Pressure describes the factors creating exertion on environment resource based	The *state* variable describes some physical measurable characteristic of the environment that results from the pressure.	Is the environmental change on ecosystem, human health and wellbeing	The response variables are those policies, actions or investments that are introduced to solve the problem
DPSIR Smeets & Weterings(1999)	Processes and anthropogenic activities (production, consumption, recreation etc) in an area (country, watershed etc)	The direct stress, deriving from the anthropogenic system and affecting the natural environment, i.e. pollutant release	Reflects the environmental conditions of the natural systems (air, soil and water quality)	A measure of the effects on humans due to changes in the state of environmental systems	The evaluations of actions oriented to solve environmental problems in terms of management strategies

et al., 1998). The first formal effort at managing the coastline was initiated in 1972 by the United States with the enacting of the Coastal Zone Management Act (United States Fish and Wildlife Service, 1972). By2005 it was reported that over 40% of the world's population lives within 80 km of the coast (and this is expected to rise more than 50% by 2025) and this advocated that coastal ecosystems will be more valuable and more vulnerable to pressures in the future (MEA, 2005). Since the early efforts by the USA in 1972, and increasingly after the MEA report in 2005, there has been a global movement through a variety of approaches to integrate and implement coastal zone management such as: ecosystem-based management (EBM), integrated coastal management (ICM), integrated coastal zone management (ICZM) and community-based coastal resource management (CBCRM) and ocean-coast management.

EBM deals with the drivers of change within the ecosystem and aims to sustain the goods and services produced. An adaptive process, designed and executed to be learning-based, it represents the shift from managing commodities to managing activities for the overall functioning of the system; from individual species and single sector management to ecosystem management (UNEP, 2006). This adaptive nature of EBM, which accommodates space, time and context specificity, allows for it to more representative of the realities experienced in nature.

Since numerous advances were made with EBM in terrestrial systems (Christensen et al., 1996), it was then applied to marine systems where the primary focus was fisheries management (Babcock and Pikitch, 2004; Browman and Stergiou, 2004), and more recent research took the concept into the coastal system (Granek et al., 2010; Tallis et al., 2010; Aswani et al., 2012; Guerry et al., 2012). Granek et al. (2010) discusses the variety of reasons coastal ecosystem-based management can fail, including inadequate science, ineffective governance and standoffs among groups who derive different benefits from ecosystems (e.g., conservation interests, coastal development, commercial fishing). This observation by Granek et al. (2010) has particular importance to SIDS as they can identify with all the challenges outlined by the author (inadequate science, ineffective governance, and user conflicts). This further begs the question of how effective coastal ecosystem-based management can be to SIDS, and when the large ocean areas (afforded through the ratification of United Nations Convention on the Law of the Sea) are considered, it becomes even more daunting.

Some of the issues identified with EBM seem to be addressed with development of ICM/ICZM. ICM, also known as integrated coastal zone management (ICZM) is described as being both an institutional framework and a process. Through its cross-sectoral planning structure, Barrania (1999) explains that ICM facilitates development plans in a way that reduces conflict, thus enhancing sustainable development while conserving natural resources (Barrania, 1999; UNEP.org, 2002) and Olsen (2003) addresses the importance of ICM in defining needs for both development and conservation in geographically specific places. Bowen and Riley (2003) emphasizes that ICM goals require clarity in determining the anthropogenic factors that influence environmental conditions. This is, in itself challenging, because to determine the exact contributions of drivers, would require complicated statistical analysis and numerous assumptions. Additionally, the data needed for statistical analysis of this nature is seriously lacking in developing countries and in particular SIDS.

Further, community-based coastal resource management (CBCRM) emerged as an innovative and locally-based form of ICZM (Landry, 2010). Pomeroy and Carlos (1997) highlighted an additional advantage of the CBCRM in that it informs local and sustainable resource management practices. CBCRM has the advantage of been community specific and adapting a bottom-up approach to management whereby local stakeholders are given a decision-making role. This has witnessed an upsurge in community-based management and resource advocacy. The reality is that this has witnessed greater donor agencies 'buy in' which has significantly helped to scale the bottom-up approaches in the research agenda and has also firmly given recognition to the

Table 2
Shortcomings of DPSIR framework.
(Source: Singh, 2005)

THEMES	SHORTCOMINGS	SOURCES
Over Simplification	The relationships between the different parts of society are over simplified in this approach when in fact these relationships are complex. In addition, it ignores the many linkages between issues and feedback within the socio-ecological system.	Seppo et al. (2003) Rapport et al.(1998) Rapport and Whitford (1999)
Static Properties	DPSIR is performed on static indicators and cannot take into account the system dynamic, for example, pollution can only be dealt with if it has already happened. The response is always reactive.	Seppo et al. (2003) Rapport et al. (1998) Rapport and Whitford (1999)
Relationships	DPSIR cannot handle cause - consequence relationships.	Seppo et al. (2003) Rapport et al. (1998) Rapport and Whitford (1999) Segnestam (2002)
Linear	It offers linear and unidirectional causal chains (cause - effect models). It cannot deal with vertical or horizontal integration.	Seppo et al. (2003) Rapport et al. (1998) Rapport and Whitford (1999) Segnestam (2002)
Analytical Ability	Environmental trends can be analysed only by repeating the indicator reports at regular intervals.	Seppo et al. (2003) Rapport et al. (1998) Rapport and Whitford (1999)
Shift of Pressure	The response to one pressure can become a pressure on another part of the system.	Garcia and Stapleton Lenz et al. (2000)

environment, resource use and human wellbeing connection. With the effects of climate change altering ecosystems on a global scale and impacting human welfare, a key issue for coastal managers is to identify where, when and how to adapt to the resulting changes. What is evident from the discussion here, is that each management approach discussed above, would improve the state of the natural environment and relieve certain pressures. However, within such a complex system as the coastal ecosystem, it is inherently challenging to measure the proportion of

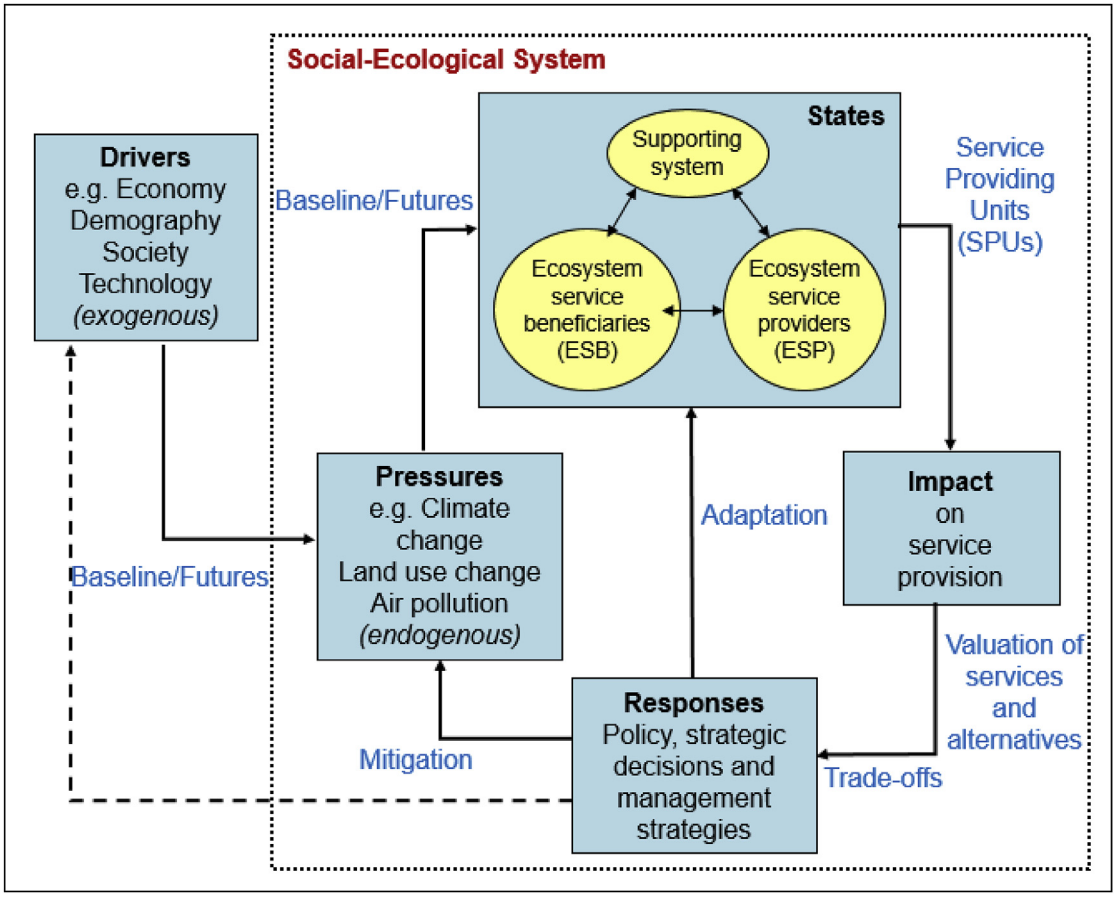

Fig. 4. The Framework for Ecosystem Service Provision (FESP) conceptual framework (Source: Rounsevell et al., 2010 reproduced with permission).

change attributable to a specific action and thereby there is the need to look at the issues according to place, time and context with significant recognition placed on the interrelationships and interdependencies that may exist among various components being investigated. This is even more relevant for SIDS.

6. Coastal ecosystem management in Caribbean Small Island Developing States (SIDS)

SIDS are perhaps the single most globally recognized group where sustainable ecosystem management has a vital role to play in all facets of development and to some extent its socio-cultural norms and practices. This is because the coastal and marine environment are critical to their livelihoods and human well-being, given the significant connectivity and concentration of the economic, social, cultural and environmental activities in their coastal zone. In order to sustain these activities and the concomitant benefits, ecosystem management and coastal science must be considered at all stages of the policy and developmental agenda and political discourse. Adhering to these principles can support sustainable development on the one hand, while on the other, failure to incorporate such principles can have severe consequences. In many Caribbean SIDS, we can find evidence of both scenarios.

The Dominican Republic is the most visited island in the Caribbean, receiving on average, five million visitors annually (CTO, 2014). One of the 'pull factors' for tourists is the rich composition of coastal and marine ecosystems ranging from sandy beaches, rocky coasts, estuaries, mangroves, marine prairies and coral reefs host around 2000 species of marine fauna, including sea anemones, sponges, jellyfish, crabs, shrimps, fish, turtles and even whales among others (Kappelle, 2009).

Promotion of the tourism sector has been a priority since the 60s through tourism incentive policies (Ruta, 2003) and as tourism development continued, so did the degradation of coastal ecosystems due to poorly enforced rights over the use of resources. A comprehensive analysis of Dominican Republic's coastal management issues by Heredia (2009) identified pollution in estuaries, coastal lagoons and the sea; the destruction of coastal vegetation and dunes; the extraction of materials for construction, such as sand from virgin beaches to rebuild depleted beaches; the destruction of sea grass beds through cleaning of the beach in tourist areas; the installation of infrastructure and engineering projects above the carrying capacity of the system; and the drying of coastal lagoons for the development of touristic infrastructure, among others.

Realizing the potential collapse of the national tourism industry, due to the continued beach deterioration (Wielgus et al., 2010), the Dominican Republic Ministry of Tourism contracted a survey of the country's beaches in March 2016. The tender subsequently published detailed regeneration works on 13 beaches for $100 million US dollars (MITUR, 2016). However, considering what now needs rectifying and what has been permanently lost, many of these issues could have been avoided through not only proper monitoring and law enforcement by the respective governing bodies, but also consultation with the scientific community prior to infrastructural development. Unfortunately, these are consequences faced by numerous Caribbean states, where for decades tourism development ensued in the coastal zone without as much information as what is now available on the numerous benefits of conserving the coastal resources (*see* Spalding et al., 2014; Narayan et al., 2017). Hazard-prone Caribbean countries within the Atlantic hurricane belt, are dependent on wetlands to lessen the impacts of storm events, thereby reducing the amount of money to repair damages (Arkema et al., 2013). In Jamaica, data from the Forestry Department reveals that over the last 15 years the country experienced a loss of approximately 95% or 2100 ha of wetlands as a result of the construction of hotels and other infrastructure (Forestry Department, 2017; Jamaica Observer, 2017). Between 2002 and 2007, the country was impacted by three major hurricanes and several flood events that caused over $73 billion in losses (Richards, 2008), a cost that could have been significantly reduced if there were more wetlands.

In Trinidad and Tobago, the Cocal area includes the Manzanilla beach in Cocos Bay and the Nariva Swamp. The Cocal sand bar or Manzanilla beach prevents salt water intrusion into the Nariva swamp from the marine environment of the Atlantic Ocean in a barrier beach complex, maintaining the necessary salinity levels for life in the Ramsar Convention protected wetland ecosystem. Singh (1997) and Darsan (2005) highlighted significant erosion along several parts of the Manzanilla beach and Darsan (2013) explained that sections of the barrier were becoming progressively narrower as the back of the barrier beach was not driven inland with coastal retreat. Due to the low-lying topography of the beach and backshore area, the sand bar has been eroded from fresh water outflow and sea water inflow; creating points where salt water can directly affect salinity in the Nariva Swamp (Environmental Management Authority, 2001). Thus, the viability and longevity of this wetland depends on the maintenance of the barrier beach.

In 2014 an extreme flooding event occurred in the Cocal area resulting in severe erosion due to prolonged heavy rainfall (Darsan et al., 2014). As the water retention capacity of the swamp was exceeded, water flow became channelized long the Manzanilla/Mayaro Main Road which lies between the beach and the wetland. Road undercutting by the water and eventually collapse ensued as channels were cut out to the sea. Damages to the main road and homes which were built on the barrier beach were the most significant effects. Coastal scientists advised on the need for establishing a national set-back policy which not only considers coastal areas, but also inland flood-prone areas as natural processes will repair the area over time in the absence of human infrastructure. However, the need to re-establish connectivity between the communities that were cut-off outweighed the scientific advice, and the roadway was re-built in its exact location.

Grande Riviere is an isolated coastal community located on the north coast of Trinidad. The main economic activity is ecotourism, driven largely by conservation efforts and recognition of the area as a prime nesting site for the endangered leatherback turtles (*dermochelys coriacea*) and the blue-throated piping-guan (*pipile cumanensis*). Thus, Grande Riviere's ecosystem is unique where environmental conditions drive livelihoods and by extension social cohesion. However, the beach where the turtles nest is constantly in a state of flux, being subjected to cyclic high-energy wave and river flooding events which causes erosion and subsequent loss of or damage to turtle eggs or hatchlings.

In 2012, the Grande Riviere river mouth shifted its course in a single flood event, leading to severe backshore channelized erosion which threatened the infrastructure of hotels and other coastal properties. The channel erosion scars were responded to with *engineering quick fixes* in the form of a sand dam with reclaimed sediment from the beach to redirect the mouth of the river to its former position. However, this mitigation was done with little adherence to the scientific information regarding the dynamics of the beach and the interaction of the ecosystem as a whole. As a consequence, it led to more erosion, especially in a turtle nesting site, leading to species mortality. Further, such engineering response led to loss of structures, infrastructural relocation and impounded stagnant water in the erosion channel (Darsan et al., 2016). Darsan et al. (2016) further explained that later that year, with the upcoming nesting season and the threats the erosion channel posed to tourists, recreational users, the community and the turtles themselves, the Government agency held consultations with the scientific community seeking advice on the best way forward. Based on the interpretation of scientific, social and economic data, it was decided that a "no-plan of action" would be adopted leaving the beach to naturally recover with the help of the seasonal winter swells. This management approach was therefore more integrated and adaptive and resulted in little to no further damage to the environment.

Such lessons learnt demonstrate that in an era of significant resource depletion and demand, ecosystem degradation, economic

instabilities, and the effects of climate change, sustainability science research in our coastal systems are becoming more urgent and required. Grande Riviere offers us a 'living laboratory' to measure and study; the cost of inaction, the benefits of timely interventions, the impacts on people and planet and the challenges and opportunities to good sustainable management and effective governance. Continuing to study environmentally sensitive areas like these can help promote better decision making in similar areas nationally, regionally and internationally. More so, such an example can serve as a research microcosm for similar sites across the SIDS in the Caribbean, Pacific and Indian Oceans.

7. Discussion and recommendations

In the quest for solutions that are widely applicable, sustainability science undertakings have created a generalized understanding of most systems (Spangenberg, 2011). This is evident from the Millennium Ecosystem Assessment. Its broad scope meant that it was unable to evaluate the interactions between the characteristics of both the social and ecological systems. Martín-López (2009) explains that the ecosystem services approach requires interdisciplinary collaboration as the discourse is usually predicated by ecologists who fail to recognize the human dimension of ecosystem dynamics, and social researchers who do not understand ecosystem functioning in the way it is responsible for the flow of ecosystem services.

However, while all these assessments have allowed for a deeper appreciation and ease in dialogue of the interlinkages, much of their application still require meaningful development of indicators of measurement and this remains a significant challenge. One of the problems is the low level of data generation. This data collection challenge leads to our inability to adequately capture resource accounting. Therefore, data clearing house mechanisms and repositories would serve to minimise this challenge.

Since coastal management decisions are concerned with balancing the preservation of natural habitat with human development initiatives, ecosystem structure and function should be linked to social values. Instead they are most often discussed through economic values as a means for cost-benefit decision making (Barbier et al., 2008; Nobre, 2009; Luisetti et al., 2011). Monetary values obscure the underlying social preferences toward ecosystem services. A non-economic evaluation should be taken to understand these motivations, but such quantifications need to be widely applicable in different contexts to support decision-making.

In classifying ecosystems Fisher et al. (2007) advises that a consideration of all parts of the ecological system is just as crucial as considering the social and political contexts within which the services are being investigated or utilized. Terms may be defined to suit the purposes and needs of a particular discipline. Callicott and Mumford (1997) made the case for conservation biology, but the same can be said of sustainable, coastal and ecosystem management individually. Conservationists, ecologists, engineers, economists, marine biologists and anthropologists all come from different fields, with different research traditions. As such, the approaches of each to problem solving seeks answers from within a particular perspective, which involves pre-existing power relations, institutions and judgements (Spangenberg, 2011; Schröter et al., 2014). A more holistic approach would be that which is proposed by Mavrommati and Richardson (2012) in which ecologically sustainable coastal development requires cooperation in: (i) scientists identifying the ecological limits and constraints that need to be observed; and (ii) economists and decision makers identifying the possibilities for economic development without violating the ecological limits proposed by natural scientists.

Inevitably, value judgements will be made in this type of research. Lele and Norgaard (1996) has suggested that researchers accept and declare this explicitly to the affected communities prior to undertaking the research, and to all users of its results. Through such an approach, enhanced communication of clear objectives between policy-makers, scientists and culturally diverse people will be achieved. Given that SIDS' experiences with climate change are used to frame the discussion beyond SIDS (De Souza et al., 2015), evidence-based decision making is not only relevant for SIDS' governments and communities, but also for international awareness of climate change impacts and development aid. Ecosystem service science is thus a way to bridge this gap, as ecosystem-based adaptation to climate change by Caribbean SIDS is considered (Medeiros et al., 2011; Mercer et al., 2012). Methodologies for ecosystem-based adaptation due to the diversity of Caribbean SIDS would produce an array of different outcomes. However, Mercer et al. (2012) argues that this will facilitate comparison of contexts and local distinctiveness across locations to reveal good-practice case studies, thereby significantly contributing to the scientific literature.

The examples provided show that in the absence of clear ecosystem management frameworks, which considers people, place, and their interactions, ill-informed actions can have devastating impacts. The implications for SIDS with limited land areas coupled with significant coastal development and investment which in many instances are the backbones to entire nations, requires that management approaches be grounded in science. Science and coastal processes play a very important role in decision making and must never be underestimated. The examples provided for Caribbean SIDS in this paper offers us an appreciation to understand the ecosystem interactions and management challenges. They further demonstrate the consequences of negating these ecosystem approaches which have devastating consequences not only on livelihoods but also on biodiversity. Research in SIDS are beneficial to this end, since the environmental processes and interactions, serve as "indicators" of tipping threshold boundaries.

8. Conclusion

Ecosystem management emerged from the demand for a sustainable approach to understand the complex interrelations between different, and at times competing elements of the environment as they work together to provide ecosystem services. Issues with interdisciplinary collaboration are numerous but while this is the basis of the greatest weakness in the science developed thus far, it is also its greatest strength as there is considerable potential to be realised. The degree to which project outputs and activities are achieved are directly related to the objectives which are defined by an individual initiative. The initial and sustained applications of these methods require a high degree of collaboration and cooperation among those participating, including those funding and administering the initiative, political leaders and, most importantly the ones directly affected.

While there are different methods to evaluating a terrestrial ecosystem, managing the coastal ecosystem with both marine and terrestrial interests is even more complex. To make strides toward sustainability, further research is required to realize the balance between ecosystem service footprints and local ecosystem service supply and demand. The adaptation or maladaptation of sustainable coastal ecosystem management practices have far reaching implications for SIDS. However, the progress in integrating the ecological, economic as well as social dimensions of ecosystem services is still in its infancy. Therefore, what is required is a concerted and collaborative effort by decision-makers and scientists to make sustainable coastal ecosystem management in SIDS a reality.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2018.06.004.

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